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FEEDBACK SYSTEM THEORY.(U)
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FEEDBACK SYSTEM THEORY.

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1. Synthesis of Systems with Linear or Nonlinear Time-Varying Uncertain Plants

One major research effort was in the extension of a synthesis technique for linear time-varying (ltv) and nonlinear time-varying (nltv) systems with significant plant parameter uncertainty. An outstanding property of the synthesis technique is its quantitative nature. One can define the bounds of parameter uncertainty and the desired performance bounds. The synthesis technique guarantees the solution of the problem, under certain restrictions. One important restriction was the 'minimum-phase' (mp) requirement for the uncertain plant set. (The synthesis technique makes the mp concept relevant in ltv and nltv systems.) Another was the restriction to finite system inputs in the nltv case. The extension of the latter to infinite input sets also forced consideration of the nonminimum-phase (nmp) case.

The ltv nmp problem was first considered. It was soon found essential to obtain a precise solution to the linear time-invariant (lti) nmp problem. Qualitatively, it is well known that if the uncertain plant set contains nmp elements, then it may be impossible to solve the problem by lti compensation--the performance specifications would then have to be relaxed. But it was necessary to make the relations more quantitative. A considerable amount of time was therefore invested in the lti nmp problem. The optimum design for this problem class was found under two constraints:

(1) If the plant has poles in a part of the right half-plane, then the

range of uncertainty of these poles should include some part of the left half-plane.

(2) The compensation inserted in the loop is mp and stable.

A great deal of the effort was expended in proving uniqueness of the optimum design--the kind of task a research engineer would hardly bother with in the past, but is now necessary due to the demand for a higher level of mathematical rigor.

The solution of the lti nmp problem helped considerably in the solution of the ltv nmp problem. Two papers resulted from the above work, both accepted for publication (1, 2). (Copies have been supplied to AFOSR.) The ground was thus prepared for tackling the much more difficult nonlinear problem. The first and current effort is in the extension to infinite input sets--resulting in the concepts of 'weakly nonminimum-phase' and 'strongly nonminimum-phase' systems. A'weakly mp' plant arises from an 'inherently mp' nonlinear plant when the latter's output is nmp. Every nonlinear plant set is 'weakly nmp' when a realistic infinite system input set is considered. The synthesis technique converts the ltv or nltv problem into an 'equivalent' linear one. Even in the 'weakly nmp' case, the 'equivalent' linear system is effectively nmp, suggesting that the problem <u>may</u> not be solvable. However, we are fairly well convinced that the nonlinear, 'inherently mp,' (but weakly nmp) problem is solvable by this technique, and have been successful experimentally. But obtaining a rigorous proof is very difficult. The mathematical approach being attempted now is to first show the existence of a solution by means of impractical compensation (more zeros than poles) in the feedback loop, and then show that the impractical compensation can be modified into a practical one, without violating the design specifications.

It is worth emphasizing that the above synthesis techniques use linear frequency response concepts and tools very familiar to the ordinary practical design engineer (perhaps not to some "modern" control theorists). The designer need not be an expert in nonlinear systems. He translates the nonlinear set into an equivalent linear set, and thereafter he works with linear frequency-response tools and concepts. It is also worth emphasizing that the method is exact and quantitative. There are no approximations made in the course of design execution.

2. Single Input-Output Multiple Loop systems with Plant Uncertainty

Suppose the plant has internal variables which may be sensed and the data used for feedback purposes. How does the designer optimally divide the feedback burden among the resulting available independent feedback loops (one for each sensor)? Can a systematic design technique be developed for this purpose? This problem has been solved for the cascaded plant shown in Fig. 1, for the case when the uncertainty in the plant sections P_1, P_2,.... are independent of each other.

The simplest noncascade multiple-loop structure is shown in Fig. 2. The optimal design was defined as that which minimizes loop bandwidths. It has been found that an optimal design is possible, by means of an extension of the cascade design philosophy. The results have been written up and submitted for publication (3) (manuscript supplied to AFOSR). Current effort is in the extension of the design technique to the more complex multiple-loop structures of Fig. 3. It is felt that at some point there will emerge an approach which will permit handling any single input-output multiple-loop structure with independent uncertainty of the plant sections.

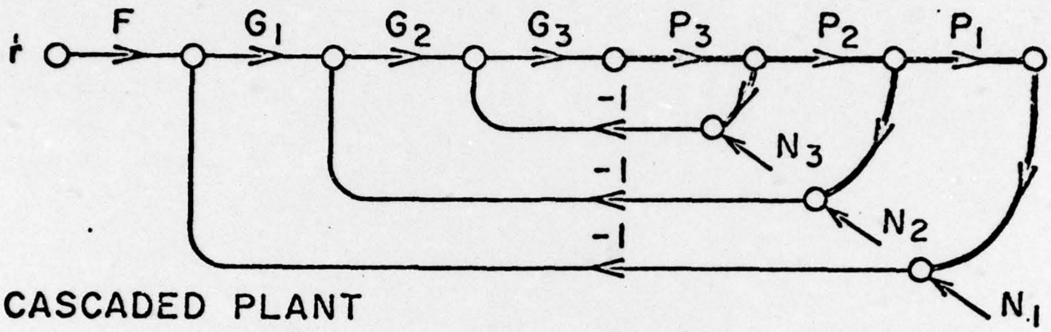
References

1. Horowitz I. and Sidi M., Optimum Synthesis of nonminimum-phase feedback systems with plant uncertainty--accepted for publication.

2. Horowitz I. and Sidi M., Optimum Synthesis of linear time-varying nonminimum-phase feedback systems with plant uncertainty--accepted for publication.

3. Horowitz I., Te-Shing Wang and Rushing G., Single input-output multiple loop feedback systems with plant uncertainty--under review.

MULTIPLE-LOOP STRUCTURES



CASCADED PLANT

Figure 1

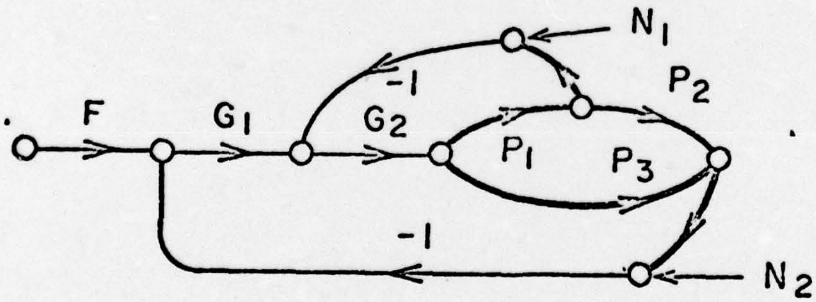


Figure 2

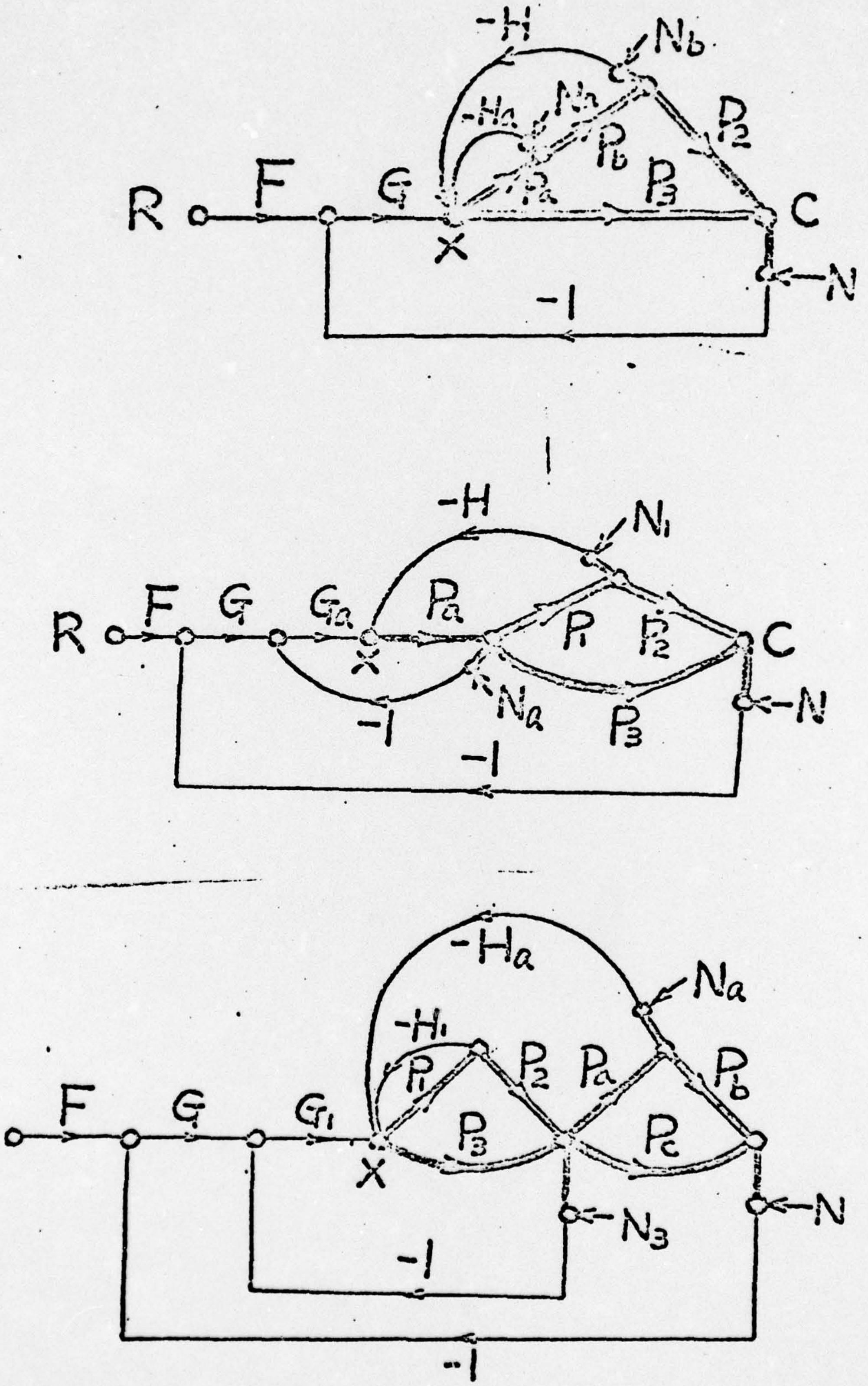


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Figure 3

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The two major research efforts were in the areas of (1) nonminimum-phase linear and nonlinear time-varying systems, and (2) multiple-loop single input-output systems. In both areas, the objective was to develop synthesis techniques to achieve assigned system performance specifications, despite significant uncertainty in a constrained part (plant) of the next page

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) system. In the first area, it was necessary to first solve the optimal linear time invariant nonminimum-phase problem. This enabled the solution of the linear time-varying nonminimum-phase problem. Progress was made on the nonlinear time-varying case. In the second area, an optimal design technique was completed for the simplest (two-loop) noncascade system, and it appears promising that the same design philosophy can be used for more complex structures.

Three papers were written, with two accepted for publication and one under review.